POWER CONTROL WITH SPACE TIME TRANSMIT DIVERSITY

FIELD OF THE INVENTION

This invention relates to wideband code division multiple access (WCDMA) for a communication system and more particularly to power control with space time transmit diversity for WCDMA signals.

BACKGROUND OF THE INVENTION

Present code division multiple access (CDMA) systems are characterized by simultaneous transmission of different data signals over a common channel by assigning each signal a unique code. This unique code is matched with a code of a selected receiver to determine the proper recipient of a data signal. These different data signals arrive at the receiver via multiple paths due to ground clutter and unpredictable signal reflection. Additive effects of these multiple data signals at the receiver may result in significant fading or variation in received signal strength. In general, this fading due to multiple data paths may be diminished by spreading the transmitted energy over a wide bandwidth. This wide bandwidth results in greatly reduced fading compared to narrow band transmission modes such as frequency division multiple access (FDMA) or time division multiple access (TDMA).

New standards are continually emerging for next generation wideband code division multiple access (WCDMA) communication systems as described in Provisional U.S. Patent Application No. 60/082,671, filed April 22, 1998, and incorporated herein by reference. These WCDMA systems are coherent communications systems with pilot symbol assisted channel estimation schemes. These pilot symbols are transmitted as quadrature phase shift keyed (QPSK) known data in predetermined time frames to any receivers within range. The frames may propagate in a discontinuous transmission (DTX) mode. For voice traffic, transmission of user data occurs when the user speaks, but no data symbol transmission occurs when the user is silent. Similarly for

packet data, the user data may be transmitted only when packets are ready to be sent. The frames are subdivided into sixteen equal time slots of 0.625 milliseconds each. Each time slot is further subdivided into equal symbol times. At a data rate of 32 KSPS, for example, each time slot includes twenty symbol times. Each frame includes pilot symbols as well as other control symbols such as transmit power control (TPC) symbols and rate information (RI) symbols. These control symbols include multiple bits otherwise known as chips to distinguish them from data bits. The chip transmission time (T_C), therefore, is equal to the symbol time rate (T) divided by the number of chips in the symbol (N).

Previous studies have shown that multiple transmit antennas may improve reception by increasing transmit diversity for narrow band communication systems. In their paper <u>New Detection Schemes for Transmit Diversity with no Channel Estimation</u>, Tarokh et al. describe such a transmit diversity scheme for a TDMA system. The same concept is described in <u>A Simple Transmitter Diversity Technique for Wireless Communications</u> by Alamouti. Tarokh et al. and Alamouti, however, fail to teach such a transmit diversity scheme for a WCDMA communication system.

Other studies have investigated open loop transmit diversity schemes such as orthogonal transmit diversity (OTD) and time switched time diversity (TSTD) for WCDMA systems. Both OTD and TSTD systems have similar performance. Both use multiple transmit antennas to provide some diversity against fading, particularly at low Doppler rates and when there are insufficient paths for the rake receiver. Both OTD and TSTD systems, however, fail to exploit the extra path diversity that is possible for open loop systems. For example, the OTD encoder circuit of FIG. 5 receives symbols S_1 and S_2 on lead 500 and produces output signals on leads 504 and 506 for transmission by first and second antennas, respectively. These transmitted signals are received by a despreader input circuit (not shown). The despreader circuit sums received chip signals over a respective symbol time to produce first and second output signals R_j^1 and R_j^2 on leads 620 and 622 as in equations [1-2], respectively.

$$R_j^1 = \sum_{i=0}^{N-1} r_j(i+\tau_j) = \alpha_j^1 S_1 + \alpha_j^2 S_2 \qquad [1]$$

$$R_j^2 = \sum_{i=N}^{2N-1} r_j(i+\tau_j) = \alpha_j^1 S_1 - \alpha_j^2 S_2 \qquad [2]$$

The OTD phase correction circuit of FIG. 6 receives the output signals R_j^1 and R_j^2 corresponding to the j^{th} of L multiple signal paths. The phase correction circuit produces soft outputs or signal estimates $\tilde{S}_1$ and $\tilde{S}_2$ for symbols S_1 and S_2 at leads 616 and 618 as shown in equations [3-4], respectively.

$$\tilde{S}_1 = \sum_{j=1}^{L} (R_j^1 + R_j^2)\alpha_j^{1*} = \sum_{j=1}^{L} 2\left|\alpha_j^1\right|^2 S_1 \qquad [3]$$

$$\tilde{S}_2 = \sum_{j=1}^{L} (R_j^1 - R_j^2)\alpha_j^{2*} = \sum_{j=1}^{L} 2\left|\alpha_j^2\right|^2 S_2 \qquad [4]$$

Equations [3-4] show that the OTD method provides a single channel estimate α for each path j. A similar analysis for the TSTD system yields the same result. The OTD and TSTD methods, therefore, are limited to a path diversity of L. This path diversity limitation fails to exploit the extra path diversity that is possible for open loop systems as will be explained in detail.

Previous methods of diversity have also failed to exploit closed-loop power control between a mobile communication system and a remote base station. Present WCDMA power control for a single transmit antenna is best understood with reference to the signal flow diagram of FIG. 7 of the prior art. Sequential time slots 700-702 of the forward link signal from a base station to a mobile system include respective pilot symbols 704-706. These pilot symbols, for example pilot symbols 704, are transmitted at time t_m to the mobile system. The mobile system receives the pilot symbols and produces a transmit power control (TPC) symbol. This TPC symbol is transmitted in the reverse link to the remote base station. The remote base station adjusts transmit power for the next forward link time slot 701 at time t_s in response to this TPC symbol. Thus, the power control system of FIG. 7 fails to exploit advantages of closed-loop power control with path diversity.

By way of comparison, the signal flow diagram of FIG. 8 illustrates proposed power control for a TSTD system of the prior art. The TSTD system alternately transmits forward link time slots 800-802 from antennas A1 and A2. Pilot symbols 806 of time slot 800 are transmitted from antenna A1 at time t_{m1} followed by pilot symbols 807 of time slot 801 from antenna A2 at time t_{m2}. Circuit 814 sums these pilot symbols and produces TPC symbol 816. This TPC symbol is transmitted in the reverse link to remote the base station. The remote base station adjusts transmit power of antenna A1 at time t_s of time slot 802 in response this TPC symbol. The TSTD method, however, is limited to a path diversity of *L*. Moreover, two time slots are required for each transmit power adjustment from time t_{m1} to time t_s. Thus, the TSTD system has an additional disadvantage of imprecise power control due to increased time between received power measurement and transmit power adjustment.

Hosur et al. previously taught a new method for frame synchronization with space time transmit diversity (STTD) having a path diversity of *2L* in U.S. Patent Application No. 09/195,942, filed November 19, 1998, and incorporated herein by reference. Therein, Hosur et al. taught advantages of this increased diversity for WCDMA systems. Hosur et al. did not teach or suggest how this improved diversity might be used to improve closed-loop power control for WCDMA systems.

SUMMARY OF THE INVENTION

The foregoing problems are resolved by a circuit designed with a measurement circuit. The measurement circuit is coupled to receive a first input signal from a first antenna of a transmitter and coupled to receive a second input signal from a second antenna of the transmitter. Each of the first and second signals is transmitted at a first time. The measurement circuit produces an output signal corresponding to a magnitude of the first and second signals. A control circuit is coupled to receive the output signal and a reference signal. The control circuit is arranged to produce a control signal at a second time in response to a comparison of the output signal and the reference signal.

The present invention improves closed-loop power control by providing at least *2L* diversity over time and space. No additional transmit power or bandwidth is required. Power is balanced across multiple antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention may be gained by reading the subsequent detailed description with reference to the drawings wherein:

FIG. 1 is a simplified block diagram of a typical transmitter using Space Time Transit Diversity (STTD) of the present invention;

FIG. 2 is a block diagram showing signal flow in an STTD encoder of the present invention that may be used with the transmitter of FIG. 1;

FIG. 3 is a schematic diagram of a phase correction circuit of the present invention that may be used with a receiver;

FIG. 4 is a block diagram of a receiver that may employ the phase correction circuit of FIG. 3;

FIG. 5 is a block diagram showing signal flow in an OTD encoder of the prior art;

FIG. 6 is a schematic diagram of a phase correction circuit of the prior art.

FIG. 7 is a signal flow diagram of a power control loop of the prior art;

FIG. 8 is a signal flow diagram of a time switched time diversity (TSTD) power control loop of the prior art;

FIG. 9A is a signal flow diagram of a space time transmit diversity (STTD) power control loop of the present invention;

FIG. 9B is a signal flow diagram of another embodiment of a STTD power control loop of the present invention;

FIG. 9C is a signal flow diagram of yet another embodiment of a STTD power control loop of the present invention;

FIG. 10A is a simulation of weighted multi-slot average (WMSA) channel estimation for STTD and TSTD for 5 Hz Doppler;

FIG. 10B is a simulation of power control for STTD and TSTD for 5 Hz Doppler;

FIG. 11A is a simulation of weighted multi-slot average (WMSA) channel estimation for STTD and TSTD for 200 Hz Doppler; and

FIG. 11B is a simulation of power control for STTD and TSTD for 200 Hz Doppler.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, there is a simplified block diagram of a typical transmitter using Space Time Transit Diversity (STTD) of the present invention. The transmitter circuit receives pilot symbols, TPC symbols, RI symbols and data symbols on leads 100, 102, 104 and 106, respectively. Each of the symbols is encoded by a respective STTD encoder as will be explained in detail. Each STTD encoder produces two output signals that are applied to multiplex circuit 120. The multiplex circuit 120 produces each encoded symbol in a respective symbol time of a frame. Thus, a serial sequence of symbols in each frame is simultaneously applied to each respective multiplier circuit 124 and 126. A channel orthogonal code C_m is multiplied by each symbol to provide a unique signal for a designated receiver. The STTD encoded frames are then applied to antennas 128 and 130 for transmission.

Turning now to FIG. 2, there is a block diagram showing signal flow in an STTD encoder of the present invention that may be used with the transmitter of FIG. 1 for pilot symbol encoding. The pilot symbols are predetermined control signals that may be used for channel estimation and other functions as will be described in detail. Operation of the STTD encoder 112 will be explained with reference to TABLE 1. The STTD encoder receives pilot symbol 11 at symbol time T, pilot symbol S_1 at symbol time $2T$, pilot symbol 11 at symbol time $3T$ and pilot symbol S_2 at symbol time $4T$ on lead 100 for each of sixteen time slots of a frame. For a first embodiment of the present invention having a data rate of preferably 32 KSPS, the STTD encoder produces a sequence of four pilot symbols for each of two antennas corresponding to leads 204 and 206, respectively, for each of the sixteen time slots of TABLE 1. The STTD encoder produces pilot symbols B_1, S_1, B_2 and S_2 at symbol times T-$4T$, respectively, for a first antenna at lead 204. The STTD encoder

simultaneously produces pilot symbols B_1, $-S_2^*$, $-B_2$ and S_1^* at symbol times *T-4T*, respectively, at lead 206 for a second antenna. Each symbol includes two bits representing a real and imaginary component. An asterisk indicates a complex conjugate operation or sign change of the imaginary part of the symbol. Pilot symbol values for the first time slot for the first antenna at lead 204, therefore, are 11, 11, 11 and 11. Corresponding pilot symbols for the second antenna at lead 206 are 11, 01, 00 and 10.

The bit signals $r_j(i+\tau_j)$ of these symbols are transmitted serially along respective paths 208 and 210. Each bit signal of a respective symbol is subsequently received at a remote mobile antenna 212 after a transmit time τ corresponding to the j^{th} path. The signals propagate to a despreader input circuit (not shown) where they are summed over each respective symbol time to produce input signals R_j^1, R_j^2, R_j^3 and R_j^4 corresponding to the four pilot symbol time slots and the j^{th} of L multiple signal paths as previously described.

	ANTENNA 1				ANTENNA 2			
SLOT	B_1	S_1	B_2	S_2	B_1	$-S_2^*$	$-B_2$	S_1^*
1	11	11	11	11	11	01	00	10
2	11	11	11	01	11	11	00	10
3	11	01	11	01	11	11	00	00
4	11	10	11	01	11	11	00	11
5	11	10	11	11	11	01	00	11
6	11	10	11	11	11	01	00	11
7	11	01	11	00	11	10	00	00
8	11	10	11	01	11	11	00	11
9	11	11	11	00	11	10	00	10
10	11	01	11	01	11	11	00	00
11	11	11	11	10	11	00	00	10
12	11	01	11	01	11	11	00	00
13	11	00	11	01	11	11	00	01
14	11	10	11	00	11	10	00	11
15	11	01	11	00	11	10	00	00
16	11	00	11	00	11	10	00	01

TABLE 1

The input signals corresponding to the pilot symbols for each time slot are given in equations [5-8]. Noise terms are omitted for simplicity. Received signal R_j^1 is produced by pilot

symbols (B_1, B_1) having a constant value (11,11) at symbol time T for all time slots. Thus, the received signal is equal to the sum of respective Rayleigh fading parameters corresponding to the first and second antennas. Likewise, received signal R_j^3 is produced by pilot symbols ($B_2, -B_2$) having a constant value (11,00) at symbol time *3T* for all time slots. Channel estimates for the Rayleigh fading parameters corresponding to the first and second antennas, therefore, are readily obtained from input signals R_j^1 and R_j^3 as in equations [9] and [10].

$$R_j^1 = \alpha_j^1 + \alpha_j^2 \quad [5]$$

$$R_j^2 = \alpha_j^1 S_1 - \alpha_j^2 S_2^* \quad [6]$$

$$R_j^3 = \alpha_j^1 - \alpha_j^2 \quad [7]$$

$$R_j^4 = \alpha_j^1 S_1 + \alpha_j^2 S_1^* \quad [8]$$

$$\alpha_j^1 = (R_j^1 + R_j^3)/2 \quad [9]$$

$$\alpha_j^2 = (R_j^1 - R_j^3)/2 \quad [10]$$

Referring now to FIG. 3, there is a schematic diagram of a phase correction circuit of the present invention that may be used with a remote mobile receiver. This phase correction circuit receives input signals R_j^2 and R_j^4 on leads 324 and 326 at symbol times *2T* and *4T*, respectively. Each input signal has a value determined by the transmitted pilot symbols as shown in equations [6] and [8], respectively. The phase correction circuit receives a complex conjugate of a channel estimate of a Rayleigh fading parameter α_j^{1*} corresponding to the first antenna on lead 302 and a channel estimate of another Rayleigh fading parameter α_j^2 corresponding to the second antenna on lead 306. Complex conjugates of the input signals are produced by circuits 308 and 330 at leads 310 and 322, respectively. These input signals and their complex conjugates are multiplied by Rayleigh fading parameter estimate signals and summed as indicated to produce path-specific first and second symbol estimates at respective output leads 318 and 322 as in equations [11] and [12].

$$R_j^2 \alpha_j^{1*} + R_j^{4*} \alpha_j^2 = (|\alpha_j^1|^2 + |\alpha_j^2|^2) S_1 \quad [11]$$

$$-R_j^{2*}\alpha_j^2 + R_j^4\alpha_j^{1*} = (|\alpha_j^1|^2 + |\alpha_j^2|^2)S_2 \qquad [12]$$

These path-specific symbol estimates are then applied to a rake combiner circuit 404 (FIG. 4) to sum individual path-specific symbol estimates, thereby providing net soft symbols or pilot symbol signals as in equations [13] and [14].

$$\tilde{S}_1 = \sum_{j=1}^{L} R_j^2\alpha_j^{1*} + R_j^{4*}\alpha_j^2 \qquad [13]$$

$$\tilde{S}_2 = \sum_{j=1}^{L} -R_j^{2*}\alpha_j^2 + R_j^4\alpha_j^{1*} \qquad [14]$$

These soft symbols or estimates provide a path diversity L and a transmit diversity 2. Thus, the total diversity of the STTD system is $2L$. This increased diversity is highly advantageous in providing a reduced bit error rate.

Referring now to FIG. 4, there is a simplified diagram of a mobile communication system that may use the phase correction circuit (FIG. 3) with closed-loop power control of the present invention. The mobile communication system includes an antenna 400 for transmitting and receiving external signals. The diplexer 402 controls the transmit and receive function of the antenna. Multiple fingers of rake combiner circuit 404 combine received signals from multiple paths. Symbols from the rake combiner circuit 404, including pilot symbol signals of equations [13] and [14], are applied to a bit error rate (BER) circuit 410 and to a Viterbi decoder 406. Decoded symbols from the Viterbi decoder are applied to a frame error rate (FER) circuit 408. Averaging circuit 412 produces one of a FER and BER. This selected error rate is compared to a corresponding target error rate from reference circuit 414 by comparator circuit 416. The compared result is applied to bias circuit 420 via circuit 418 for generating a signal-to-interference ratio (SIR) reference signal on lead 424.

Pilot symbols from the rake combiner 404 are applied to the SIR measurement circuit 432. The SIR measurement circuit produces a received signal strength indicator (RSSI) estimate from an average of received pilot symbols. The SIR measurement circuit also produces an interference signal strength indicator (ISSI) estimate from an average of interference signals from base stations

and other mobile systems over many time slots. The SIR measurement circuit produces an SIR estimate from a ratio of the RSSI signal to the ISSI signal. This SIR estimate is compared with a target SIR by circuit 426. This comparison result is applied to TPC command circuit 430 via circuit 428. The TPC command circuit 430 sets a TPC symbol control signal that is transmitted to a remote base station. This TPC symbol instructs the base station to either increase or decrease transmit power by preferably 1 dB for subsequent transmission.

Referring now to FIG. 9A, there is a signal flow diagram of an embodiment of closed-loop power control for a STTD system of the present invention. The STTD system transmits forward link time slots 900-902 from antenna A1 in parallel with forward link time slots 910-912 from antenna A2. Pilot symbols 903 of time slot 900 from antenna A1 and pilot symbols 913 of time slot 910 from antenna A2 are transmitted at time t_m. Circuit 918, included in SIR measurement circuit 432 (FIG. 4), sums these pilot symbols. The sum is compared to a target SIR on lead 424. A result of the comparison is applied to TPC command circuit 430 via circuit 428. The TPC command circuit produces TPC symbol 920 (FIG. 9A) for transmission to the remote base station in the reverse link. The remote base station adjusts transmit power of antenna A1 for time slot 901 and transmit power of antenna A2 for time slot 911 at time t_s in response this TPC symbol. This method of closed-loop transmit power control is highly advantageous in regulating transmit power with minimum variance. Channel estimates and corresponding pilot symbol signal estimates are greatly improved by STTD. Accuracy of subsequent measurement of these received pilot symbol signal magnitudes is greatly improved. Transmit power variance is minimized for both antennas A1 and A2 by transmit power adjustment in a time slot immediately following the measured pilot symbol signal time slot.

Turning now to FIG. 9B, there is a signal flow diagram of another embodiment of closed-loop power control for a STTD system of the present invention. The STTD system transmits forward link time slots 930-932 from antenna A1 in parallel with forward link time slots 940-942 from antenna A2. Pilot symbols 933 of time slot 930 from antenna A1 are transmitted at time t_{m1}. The SIR measurement circuit 432 (FIG. 4) measures these pilot symbols and compares them with a

target SIR on lead 424. The TPC command circuit 430 produces TPC symbol 947 (FIG. 9B) for transmission to the remote base station in the reverse link. The remote base station adjusts transmit power of antenna A1 for time slot 931 at time t_{s1} in response this TPC symbol. Pilot symbols 944 of time slot 941 from antenna A2 are transmitted at time t_{m2}. The SIR measurement circuit 432 (FIG. 4) measures these pilot symbols and produces TPC symbol 950 (FIG. 9B) for transmission to the remote base station in the reverse link. The remote base station adjusts transmit power of antenna A2 for time slot 942 at time t_{s2} in response this TPC symbol. This embodiment of the present invention, therefore, provides a further advantage of independent power control of each transmit antenna. Transmit power variance is minimized by adjusting transmit power for each antenna in a time slot immediately following the measured pilot symbol signal time slot.

The signal flow diagram of FIG. 9C illustrates yet another embodiment of closed-loop power control for a STTD system of the present invention. The STTD system transmits forward link time slots 960-962 from antenna A1 in parallel with forward link time slots 970-972 from antenna A2. Pilot symbols 963 of time slot 960 from antenna A1 and pilot symbols 973 of time slot 970 from antenna A2 are transmitted at time t_m. The SIR measurement circuit 432 (FIG. 4) measures each of these pilot symbols and compares them to a target SIR on lead 424. A result of the comparison is applied to TPC command circuit 430 via circuit 428. The TPC command circuit produces TPC symbols 984 and 985 (FIG. 9C) corresponding to antennas A1 and A2, respectively. Both TPC symbol signals are transmitted to the remote base station in the same time slot of the reverse link. The remote base station independently adjusts transmit power of antennas A1 and A2 at time t_s in response to TPC symbols 984 and 985, respectively. This method of closed-loop transmit power control is highly advantageous in regulating transmit power with minimum variance. Transmit power of each antenna A1 and A2 is independently controlled. Transmit power variance is minimized for both antennas2 by transmit power adjustment in a time slot immediately following the measured pilot symbol signal time slot.

Referring now to FIG. 10A, advantages of the present invention will be explained in detail with reference to the simulation of weighted multi-slot average (WMSA) channel estimation for

STTD and TSTD for 5 Hz Doppler. The simulation curves show a coded bit error rate (BER) for a range of ratios of energy per bit (Eb) over noise (N0). The 5 Hz Doppler corresponds to mobile station movement with respect to a base station at walking speed. For a coded BER of preferably 10^{-3}, STTD shows approximately 0.75 dB improvement with respect to TSTD. Both show significant improvement over OTD. The simulation curves of FIG. 10B compare power control for STTD and TSTD for 5 Hz Doppler. For example, STTD shows approximately 0.9 dB improvement over TSTD for a coded BER of preferably 10^{-3}.

Simulation curves of FIG. 11A show a coded bit error rate (BER) for a range of Eb/N0 for WMSA channel estimation at 200 Hz Doppler, corresponding to mobile station movement with respect to a base station at a vehicular speed of 120 kmph (80 mph). The STTD system shows approximately 0.25 dB improvement with respect to OTD at a coded BER of preferably 10^{-3}. A similar advantage over TSTD is likely in view of the similarity of TSTD and OTD curves. Likewise, for a preferable coded BER of 10^{-3}, the curves of FIG. 11B show a 0.75 dB improvement in power control for STTD over TSTD for 200 Hz Doppler.The STTD system, therefore, provides significantly improved BER over OTD and TSTD systems of the prior art.

Although the invention has been described in detail with reference to its preferred embodiment, it is to be understood that this description is by way of example only and is not to be construed in a limiting sense. For example, advantages of the present invention may be achieved by a digital signal processing circuit as will be appreciated by those of ordinary skill in the art having access to the instant specification. Furthermore, the advantages of STTD accuracy and independent transmit antenna power control as described in FIG. 9C may be achieved with a single TPC symbol signal. A QPSK TPC symbol signal includes four states, including two states for each of the real and imaginary components. The real components, for example, may correspond to antenna A1 and the imaginary components may correspond to antenna A2. Thus, a state of the real or imaginary component of a single TPC symbol may be used to independently adjust transmit power of antenna A1 or antenna A2, respectively.

Moreover, advantages of the present invention may be extended to four transmit antennas by including the previously described STTD symbol pattern (FIG. 2) as an overlay of the OTD (FIG. 5) or TSTD (FIG. 8) symbol patterns. The STTD overlay pattern for OTD with four antennas is given by equation [15].

$$\begin{vmatrix} Ant_1 \\ Ant_2 \\ Ant_3 \\ Ant_4 \end{vmatrix} = \begin{vmatrix} a & b & a & b \\ -b^* & a^* & -b^* & a^* \\ c & d & -c & -d \\ -d^* & c^* & d^* & -c^* \end{vmatrix} \qquad [15]$$

This STTD overlay pattern for OTD substitutes the STTD symbol pattern of FIG. 2 for each OTD symbol of FIG. 5. For example, the four upper-left matrix elements $\lfloor a \quad b \quad -b^* \quad a^* \rfloor$ of equation [15] correspond to STTD symbols $\lfloor S_1 \quad S_2 \quad -S_2^* \quad S_1^* \rfloor$ of FIG. 2. These four elements of equation [15] and the four top-right duplicate matrix elements correspond to elements $[S_1 \quad S_1]$ on lead 504 (FIG. 5). Likewise, the four bottom-left matrix elements and the four bottom-right matrix elements of equation [15] correspond to elements $[S_2 \quad -S_2]$ on lead 506 (FIG. 5). An STTD overlay pattern for TSTD is given by equation [16] where ϕ corresponds to null elements when alternate antennas are transmitting.

$$\begin{vmatrix} Ant_1 \\ Ant_2 \\ Ant_3 \\ Ant_4 \end{vmatrix} = \begin{vmatrix} a & b & \phi & \phi \\ -b^* & a^* & \phi & \phi \\ \phi & \phi & c & d \\ \phi & \phi & -d^* & c^* \end{vmatrix} \qquad [16]$$

It is understood that the inventive concept of the present invention may be embodied in a mobile communication system as well as circuits within the mobile communication system. It is to be further understood that numerous changes in the details of the embodiments of the invention will be apparent to persons of ordinary skill in the art having reference to this description. It is contemplated that such changes and additional embodiments are within the spirit and true scope of the invention as claimed below.